Scientific Objective 7: Magnetospheric Sun and Weather Relationships

The purpose of scientific objective 7 is to study the magnetospheric aspects related to Sun and weather relationships.

Introduction

The subject of a possible relationship between solar activity and meteorological variables has intrigued scientific investigators for many years. A recent report [Shapley and Kroehl, 1979] lists over 1300 references to relatively recent papers alone. Unfortunately, it is difficult to test such relationships with certainty because of the high level of random variability in the meteorological quantities of prime concern and the relative infrequency of large solar events.

Modern interest in the subject dates from the work of Roberts and Olson (1973a and 1973b) when they introduced the vorticity area index and showed a correlation with geomagnetic activity. Wilcox et al. (1973 and 1974) showed how the index that represents the area of most intense vorticity in troughs in the Northern Hemisphere north of 20°N reaches a minimum about a day after a sector boundary crossing, which is a well-defined solar-terrestrial event. (See fig. 1.) These data have been reanalyzed by Shapiro (1976) and by Hines and Halevy (1975) with the conclusion that the association, while not as great as first suggested by Wilcox, does appear to be real.

The influence of solar activity on weather has been viewed with skepticism in the absence of widely accepted physical mechanisms. At two conferences in 1978 (Yosemite, California, February 8-11; Columbus, Ohio, July 24-28), the merits of various mechanisms have been debated at length. None has prevailed up to now, through the lack of evidence establishing the intermediate links in the causative chain. It is therefore important to study possible mechanisms for solar effects on weather in as quantitative a manner as possible so that those mechanisms that are not found to be viable can be discarded.

The relationships between solar disturbances and changes in atmospheric structure are best studied by prolonged observational programs involving geostationary satellites, for instance, rather than by experiments on relatively brief sortie missions. However, there are several magnetospheric aspects which involve the processes by which the energy is deposited in the atmosphere, where a lidar experiment may play a significant role, if accompanied by an extensive supporting program of ground, rocket, and balloon measurements. The probable availability of the Upper Atmosphere Research Satellite during at least some of the lidar missions offers the possibility of extending in time some of the global measurements associated with this problem.

Possible Mechanisms

There is no lack of suggestions as to ways in which short-term solar variability may affect the atmosphere. They include those mechanisms in which solar

effects on the thermosphere are transmitted to lower levels and those in which the troposphere or stratosphere is affected directly.

Roberts and Olson (1973a) suggested that penetrating ionizing radiation might produce ions in the middle atmosphere that could form condensation nuclei and produce subvisible cirrus, which would then affect the radiative balance and hence the vorticity. Lidar measurements could play a key role in testing this idea.

Another possibility would arise when energetic particles are deposited in the high-latitude thermosphere and produce strong heating which excites a disturbed thermospheric wind field. This disturbed wind field will couple with the ionization present throughout the thermosphere and with the Earth's magnetic field and will produce electric fields and currents that are characteristic of the disturbed dynamo current system. This same electric field is responsible for the magnetospheric convection of ionization and of trace constituents such as metal ions deposited by meteor trails in the lower thermosphere. It is further known from balloon measurements that these magnetospheric electric fields are conducted into the stratosphere; and it is possible that they may produce nucleation effects, having implications for the energetics of the troposphere-stratosphere system. It is also possible that their disturbance of the normal global stratospheric current system may impinge on thunderstorm electrification and therefore indirectly on cyclogenesis.

It seems unlikely that the dynamic effect of the disturbed circulation would penetrate to lower altitudes, as the energy fluxes involved are quite small compared with those required to affect the stratosphere or troposphere.

A final thermospheric effect that might be relevant is the augmentation of minor thermospheric species such as nitric oxide by particle input. Such constituents can make their way into the mesosphere where they may well profoundly affect the chemistry of other constituents such as ozone. Thermal perturbations will result from changes in absorption of near-ultraviolet radiation by the ozone, and these thermal effects may impinge on the transmission or reflection of tropospherically generated planetary-wave propagation through the mesosphere. For example, a reflected planetary wave has a large energy content in the mesosphere and might have a significant effect on cyclogenesis when it reappears in the upper troposphere.

As far as those effects involving the troposphere or stratosphere directly are concerned, most of these involve ozone in one way or another. Enhanced fluxes of solar protons associated with solar-wind sector boundaries can produce strong enhancements of the ozone layer; these will be quite nonuniform over the globe and will produce strong dynamical effects. Excess absorption of solar ultraviolet radiation will produce thermal forcing of stratospheric planetary waves whose energy may suffice to perturb the lower stratosphere sufficiently to affect synoptic-scale processes. An alternate suggestion is that short-term changes in the composition of solar near-ultraviolet radiation may change the ozone layer and produce a similar forcing effect.

A final direct effect on the stratosphere may be the energetic particle effect on its ionization content, and therefore its conductivity. Through the

current system associated with the fair-weather electric field mentioned above, this may again affect thunderstorm electrification processes. This does not by any means exhaust the list of suggested mechanisms, but suffices to show the importance of measurements of thermospheric and stratospheric chemistry and dynamics.

Magnetospheric Convection Patterns of Mg^+

One tracer for the electric-field pattern in the low-altitude magnetosphere is the distribution of alkali metals such as Mg^+. These are convected from the low-latitude E-region to much higher altitudes and latitudes, where they have been seen by satellite probes [Hanson and Sanatani, 1971] and by ultraviolet photometry of their resonant fluorescence in sunlight [Gérard, 1976]. The lidar (experiment 8) is capable of observing these metals, and the orbit-to-orbit change in their distribution will give a measure of the magnitude and variability of the electric fields.

Correlative measurements include in situ measurements of the field from satellites, measurements of the field in the stratosphere from balloons, the magnetic variations at ground level arising from the ionospheric current system, and incoherent scatter measurements at several latitudes of the ionospheric drift velocity.

Chemical Coupling From Thermosphere to Mesosphere

Large amounts of nitric oxide are known to be produced in the auroral zone during intense auroral activity (such as that associated with a substorm). This long-lived constituent is carried to lower latitudes and down into the D-region, where it is thought to be responsible for the "winter anomaly" in D-region ionization. The catalytic destruction of ozone by nitric oxide may be one link in the chain by which atmospheric dynamics is finally affected.

Nitric oxide has been observed by resonance fluorescence in the γ-bands both by rocket and by satellite; however, the former lacks horizontal coverage while the latter is incapable of producing an accurate vertical profile because of Rayleigh scattering and other effects. An ultraviolet lidar (experiment 25) would provide new results on the association of the global spread of nitric oxide with substorms and sector crossings, particularly in conjunction with ground and rocket measurements of the D-region. Mesospheric temperatures measured by a sodium lidar (experiment 14) would show resultant thermal perturbations.

Ozone Heating Effects on Circulation

Changes in the circulation of the atmosphere are usually associated with the forcing of planetary waves or tides, depending on the global nature of the change. Ozone heating can produce such changes at high altitudes, which communicate kinetic energy downwards into the lower atmosphere, perhaps by modifying either the polar night jet or the propagation of planetary waves from the

troposphere. Here, measurements by lidar of the atmospheric and thermospheric velocity field, using aerosols (experiment 20) and sodium (experiment 14), for example, should show the propagation processes at work. The temperature field should be mapped simultaneously; and meteorological rockets, meteor radars, partial-reflection drift experiments, and mesosphere/stratosphere/troposphere (MST) VHF radars will supplement conventional rawinsondes to give the atmospheric state on a coarser scale for comparison. Measurements by lidar of ozone and other constituents by DIAL (experiment 18) or occultation (experiment 13) would be needed to evaluate the ozone coupling effect.

The following table summarizes the requirements for scientific objective 7:

Parameter	Altitude range, km	Δx, km	Δz, km	Accuracy	Experiment
E	100 to 500	200	20	1 mV/m	8, 11
NO	60 to 150	200	5	20 percent	13, 25
NO	[a]25 to 150	200	5	20 percent	13, 25
V_x	60 to 150	200	10	10 m/s	14
V_x	[b]80 to 150	500	20	20 m/s	14
O	100 to 200	500	10	10 percent	26
O_3	30 to 90	200	5	10 percent	12, 13
T	50 to 150	1000	5	10 K	14

[a]During polar-cap absorption event.
[b]During geomagnetic disturbances.

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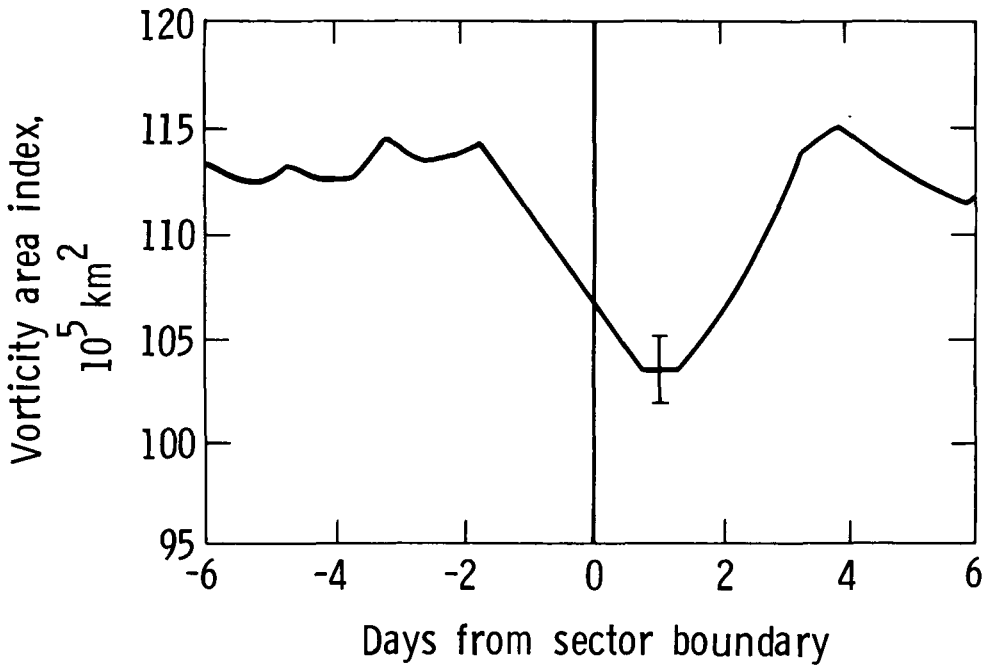

Figure 1.- Average response of vorticity area index to solar magnetic sector structure during winter period. Sector boundaries were carried past Earth by solar wind on day zero. (From Wilcox et al., 1974, courtesy American Meteorological Society)